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THE GEOLOGY OF THE COASTLINE OF WARATAH BAY BETWEEN WALKERVILLE AND CAPE LIPTRAP

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Abstract

A study of nine miles of the Waratah Bay coastline has been made, and a larger area, the Cape Liptrap peninsula, is referred to in a discussion of the structural geology and geomorphology.

Four sedimentary and two igneous formations have been mapped. Examination of fossils has established that Tremadocian (Lower Ordovician) sheared calcareous shales and siliceous limestones, and Devonian limestones, sandstones and shales are present. A group of altered basic lavas, basic intrusive rocks, pyroclastics and sediments, referred to as diabase, is probably equivalent to the Heathcotian rocks.

The Palaeozoic formations are separated by faults, gabbro being intruded along the fault between the diabase and the Tremadocian sediments. The relation of the gabbro to the Devonian is not known. The Devonian sandstones and shales have been more severely folded than the other Palaeozoic rocks and are believed to occupy a synclinal area between the structural axes of the diabase and the Tremadocian to the east, and Upper Ordovician to the west.

A mantle of Tertiary sands and conglomerates covers the older rocks, this being regarded as a marine platform which was raised during the late Tertiary uplift of South Gippsland to form a coastal plain. The coastal plain is in a youthful stage.

Structure and texture of the rocks have played an important role in the present configuration of the coastline. Erosional processes along the shore are discussed.

Introduction

Waratah Bay is the stretch of water between Cape Liptrap and Wilson's Promontory, South Gippsland, Victoria. The area surveyed is a nine-mile strip of the western coastline of Waratah Bay south from the township of Walkerville to Cape Liptrap. For discussion of the structure and geomorphology reference is made to the Cape Liptrap peninsula (Fig. 1).

The Cape Liptrap peninsula is an undulating plateau, about 30 square miles in area, with a low but dominant ridge forming a local divide striking approximately S 30° W from Rock Hill (530 feet) to Cape Liptrap, which is approximately 300 feet above sea level (Fig. 1). A number of small creeks drain into the sea on each side of the ridge. Morgan's, Middle and Ten Mile Creeks are the largest on the western side. Outcrops are rare because of the extensive layer of Tertiary gravels and sands and recent wind-blown sand mixed with plant humus.

The coastline is rock and, except for Maitland beach, is bounded by cliffs up to 100 feet high. The headlands rise abruptly from wave-cut platforms and the cliffs at Cape Liptrap are about 250 feet high. Digger Island, about 80 yards across and 250 yards in circumference, is a tied island at half tide. Rock stacks occur off the headlands of limestone and most of the these are connected to the mainland at low tide.

Walkerville may be reached by road or rail (to Fish Creek) from Melbourne. By road the distance is 103 miles via Leongatha and Fish Creek or 110 miles via Leongatha and Tarwin. Fish Creek railway station is 100 miles from Melbourne and the road from Fish Creek to Walkerville is 16 miles. This road is in bad condition during wet weather.

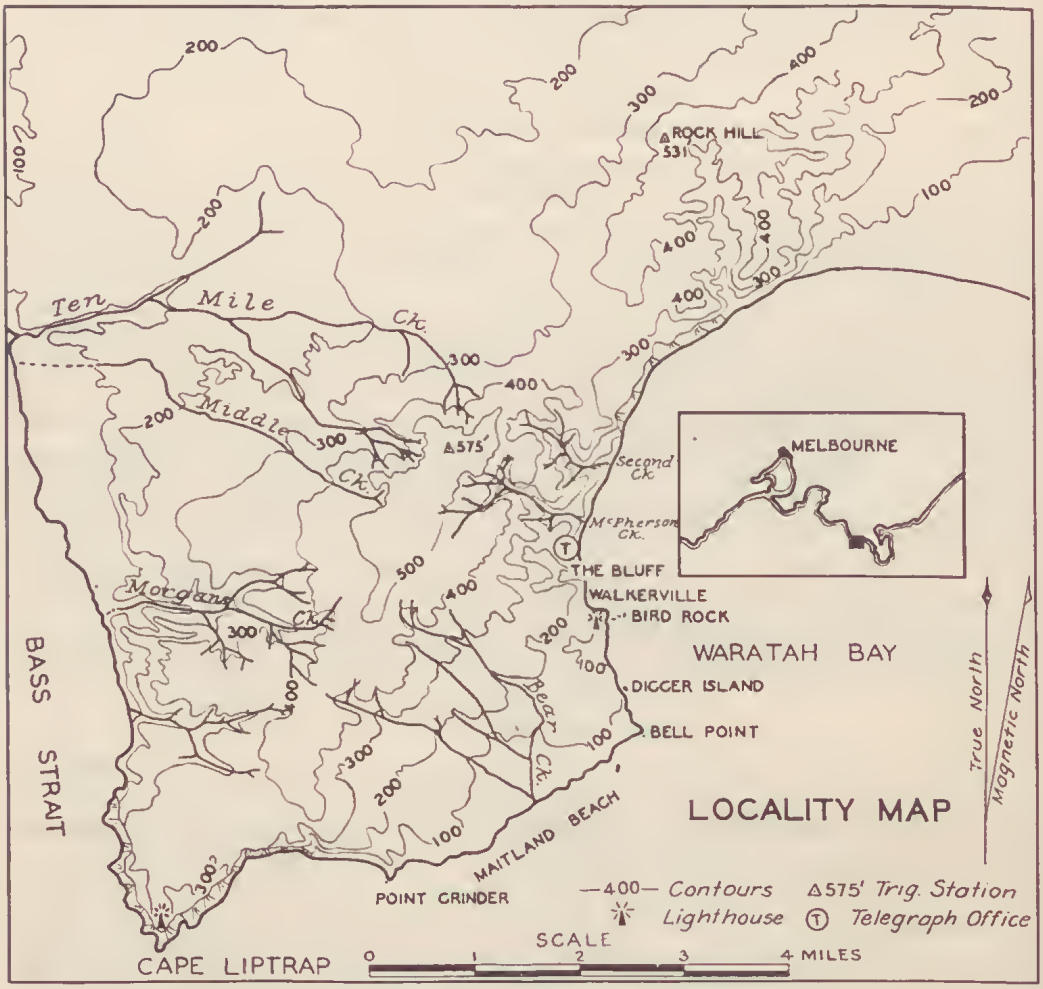

FIG. 1.

Field work extended over four short periods between 1945 and 1950. In February, 1948, a continuous compass and pace traverse was made along the shore from The Bluff to Point Grinder, together with two short chain and compass traverses in the vicinity of Bell Point. No traverses with linear control have been made between Point Grinder and Cape Liptrap. As most of the outcrops are exposed on the foreshore, field work was planned to coincide with low tides.

The locality map (Fig. 1) is based on the 1 mile = 1 inch military survey sheets of Waratah and Yanakie. The detailed inset (Fig. 2) and the areal geological

GEOLOGICAL MAP OF PART OF WARATAH BAY

BOUNDARY OF TERTIARY SEDIMENTS AFTER FERGUSON; MODIFIED ALONG THE COASTLINE

LEGEND

TERTIARY SEDIMENTS

LIPTRAP FORMATION

BELL POINT LIMESTONE

DIGGER ISLAND FORMATION

GABBRO

DIABASE

DIP AND STRIKE OF BEDS

DIP AND STRIKE OF JOINTS

FAULTS — DEFINITE; PROBABLE; DEFINITE CONCEALED; PROBABLE CONCEALED

GEOLOGICAL BOUNDARIES — DEFINITE; APPROXIMATE

LOCALITIES — ⑦ WITH FOSSILS BELOW HIGH WATER LEVEL

CREEKS — NON-PERENNIAL

ROADS

BRIDLE TRACK

True North

Magnetic North

SCALE

20 10 5 0 10 20 40

CHAINS

THE BLUFF

Bluff Creek

WALKERVILLE

Bird Rock

Corduroy Creek

Bear Creek

DIGGER I.

BELL POINT

Mushroom Rock

Livingstone Creek

BEACH

MAITLAND

WARATAH BAY

POINT GRINDER

CAPE LIPTRAP

FIG. 3

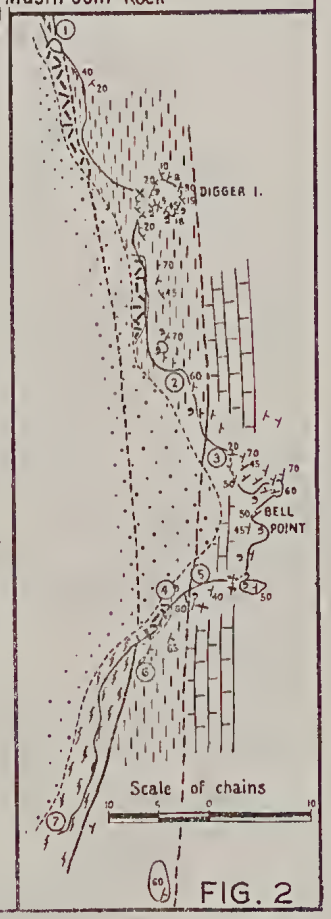

FIG. 2

map (Fig. 3) have been constructed from traverse data and the military, parish and geological plans of Waratah.

Previous field work in the area was done by officers of the Geological Survey of Victoria. Murray (1876), during a survey of South Gippsland, was the first geologist to visit the area. He reported on the occurrence of limestone at Point Grinder and Bird Rock, and brought back samples of limestone and diabase for analysis, and a collection of corals. Ulrich mentioned fossils in the Progress Report for 1875 and suggested an Upper Silurian or Lower Devonian age for the limestone. A description of the gabbro appeared in the Progress Report of the Survey in 1877 and in the same report McCoy recorded the presence of *Palaeopora* (= *Heliolites*) *interstincta* (Wahl). In 1894, Stirling investigated the deposits of silver in the contact zone of the gabbro with the Tremadocian sediments. However, the silver is not present in payable quantities. Stirling also mentioned that the Tertiary sediments near the coast had been sluiced for gold.

In 1898, Etheridge Jnr. reported on a collection of corals from Waratah Bay and named a new species, *Tryplasma murrayi*. Crinoidal limestone, a dorsal valve of a spiriferid and indeterminable plant remains are also recorded. Etheridge regarded the age as Upper Silurian. In 1904, Hall identified an imperfect specimen of *Diplograptus* from Bald Hill, eight miles north-north-west of Walkerville, and an Upper Ordovician age was established for outcrops near Ten Mile Creek and Bald Hill.

Osmiridium, in the beach sands, was recorded in 1914. Kitson, in 1917, observed that sediments at Waratah Bay contained a similar suite of fossils and were lithologically similar to the Mt. Ida beds in the Heathcote District. Lignitic material was discovered near Digger Island in 1925, when Baragwanath examined an alleged deposit of bitumen at that locality. Ferguson completed the first geological survey of the Liptrap Peninsula and his geological map was published in 1928 in the Parish Series of the Geological Survey of Victoria. A complete list of references to Waratah Bay is included in the bibliography.

Stratigraphy

Nomenclature

Four sedimentary and two igneous formations have been recognized in the area. A detailed study of trilobites collected from the sediments at Digger Island has been made by Dr. O. P. Singleton (manuscript) and he has established a Tremadocian age for these sediments. The faunal assemblage is new for Australia and the sedimentary succession has been called the Digger Island Formation. Fossil material collected from other sedimentary rocks allows only general indications of the age of the sedimentary formations to be made. Two formations of Devonian age have been named, the Bell Point Limestone and Liptrap Formation, as there are distinct lithological variations from rocks of similar age elsewhere in Victoria. Correlation with other sections in Victoria cannot be attempted without more palaeontological and stratigraphical evidence and therefore the following formation names are suggested: Digger Island Formation, Bell Point Limestone, and Liptrap Formation.

The conglomerate and sands which overlie the Palaeozoic rocks are probably of Tertiary age but have not been specifically named. The term 'diabase' is applied in the sense that it is used in Victoria to describe collectively a complex series of

altered basic and intermediate lavas with interbedded pyroclastics, ash beds and sediments of pre-Upper Cambrian age. Lithology and regional structure of the diabase is the only evidence to correlate the group with the Heathcotian formation of the Mt. William-Heathcote-Colbinabbin belt or the Mt. Wellington and Howqua areas.

Gabbro is retained as a name for the basic intrusive rock, although several basic rock types appear to have been present originally. However, the rock has been serpentinized and no outcrops of the primary rock types are known.

Sedimentary Rocks

Digger Island Formation

Definition. The Digger Island Formation is a sequence of fossiliferous, yellow-brown, grey and grey-green shales and calcareous shales; poorly bedded, yellow decalcified mudstone and thin-bedded, fossiliferous, grey, grey-green and purple, fine-grained, dense, siliceous limestones. The sediments are strongly sheared and estimated to be 120 to 130 feet thick. They are well developed on Digger Island, which has been chosen as the type locality. On its western boundary the formation is either intruded by gabbro or faulted against the diabase; on its eastern boundary it is faulted against the Bell Point limestone.

Distribution. The formation extends from locality 1 southwards beyond Digger Island, passes to the west of Bell Point, where it is faulted against the Bell Point Limestone, and reappears in the cliff face at locality 4 as deeply weathered outcrops of yellow, sheared, nodular, calcitic mudstone. At locality 6 there is a contact with the gabbro, and from there to locality 7 the formation is faulted against the diabase. The black-stained, unfossiliferous limestone stack off locality 7 is made up of rocks belonging to this formation.

Lithology. Shale and mudstone with a varying carbonate content are the dominant rock types. The thin-bedded, siliceous limestone contains calcareous nodules. Sharp lateral changes from one rock type to another are common.

Along the shoreline north from Digger Island to locality 1 and south to locality 2 the formation has been contact metamorphosed by the gabbro, which recrystallized and reconstituted the sediments for 70 to 80 feet from the contact with complete loss of bedding, destruction of fossils and development of jointing. Beyond about 150 feet from the contact, the noticeable effect of metamorphism ceases, the bedding becomes apparent and jointing is less pronounced.

Thin sections, cut from specimens taken within 40 feet of the contact with the gabbro near locality 1, indicate the variable composition of the sediments of the Digger Island Formation. Under the microscope, one section is seen to contain angular quartz grains up to 0·3 mm. in diameter. Plagioclase is also present. The rock has a fine-grained, banded matrix of a carbonate mineral and clay minerals. Other sections contain a high proportion of fibrous brucite associated with clusters of granular vesuvianite up to 1 mm. in diameter. A carbonate mineral occurs as subhedral crystals usually less than 0·1 mm. in diameter in the matrix. Euhedral pyrite, about 0·1 mm. in size, is common in all sections. Although qualitative acid tests failed to indicate the presence of dolomite or magnesite in the various types of unmetamorphosed sediments, magnesium is evidently present in places. The presence of a carbonate mineral and quartz in a thermally metamorphosed rock indicates that the intrusion of the gabbro was accompanied by a very low grade thermal metamorphism.

Palaeontology. A faunal assemblage of trilobites and brachiopods, peculiar in Australia, was found by Mr. P. W. Crohn and the writer. Brachiopods occur near locality 2 on the mainland (Fig. 2), on the south and east sides of Digger Island, and are associated with trilobites at about high water level on the south-west and west sides of the island. Trilobites are known from several localities on the north and west sides of Digger Island and below high water level on the west side of the island. Trilobite fragments occur at locality 4.

Although the fossils are sheared they are well preserved. The trilobites are as follows:

Geragnostus laterhachis sp. nov. Singleton m.s.
Geragnostus laterhachis forma *obsoleta* nov. Singleton m.s.
Kainella occidentalis sp. nov. Singleton m.s.
Leiostegium elongatum sp. nov. Singleton m.s.
Hystricunus sulcatus sp. nov. Singleton m.s.
Onchonotus rectifrons sp. nov. Singleton m.s.
Archacharpes mirabilis gen. et sp. nov. Singleton m.s.
Protopliomerops quadrispinosus sp. nov. Singleton m.s.
Phumacephalus insuetus gen. et sp. nov. Singleton m.s.
Gen. et sp. nov. undetermined.
Trilobite indet.
Pygidium unidentified.

Dr. Öpik has undertaken the examination of the brachiopods. Cystid plates are also present (Singleton, personal communication).

Dr. Singleton has stated (person communication) that the presence of the *Kainella-Leiostegium* association in the trilobite fauna of the Digger Island Formation indicates an early Tremadocian age for these beds. The general easterly dip of the sediments on Digger Island indicates that the trilobite beds are stratigraphically lower than those bearing brachiopods. Jointing and frequent small-scale faulting make it impossible to trace the beds laterally with any certainty and the relationship of the fossils on the mainland to those of Digger Island is not known.

Dr. Öpik (personal communication) has suggested lithologic affinities of the formation with a part of the Caroline Creek shales and sandstones of Tasmania (Lewis, 1940).

Bell Point Limestone

Definition. This formation consists of well bedded, fossiliferous, grey, silty limestone; bedded to massive, grey-white limestone, partly recrystallized and not richly fossiliferous, with local development of bioherms; fossiliferous, brown, silty limestone with angular chert fragments and fine micaceous mudstone. At Bell Point, the type locality, the formation is terminated on the west by a fault separating it from the Digger Island Formation and the base of the section forms the coastline on the east. At Point Grinder, and between Bird Rock and The Bluff, the formation is faulted against the Liptrap Formation on the west and against the diabase on the east; 350 feet of sediments have been measured, but the total thickness of the formation is greater than this.

Lithology. The grey, silty limestone is a dense, fine-grained, dark-coloured rock, commonly veined by calcite. The beds range from two to nine inches in thickness and are, in places, massive. These are interbedded with an evenly bedded light grey limestone, with beds ranging from six to twelve inches in thickness.

Thickness of the grey limestones is estimated to be at least 140 feet. The limestone was quarried and calcined at The Bluff for many years.

A large crudely bedded mass of grey-white limestone (about 100 × 100 × 30 feet), between the north arm of Bell Point and Mushroom Rock, is regarded as a bioherm. Beds lateral to the top of the bioherm contain angular fragmental limestone. Elsewhere, the grey-white limestone is poorly bedded or massive. It is a dense, medium-grained, clastic, pure crystalline rock and is oolitic on the inner stack at Bird Rock. One hundred and forty feet of this limestone is exposed at Bell Point and 420 feet at Point Grinder.

Angular chert fragments up to 12 mm. in diameter are embedded in the fossiliferous, brown, silty limestone and massive brown mudstone. Beds of similar lithology to the grey silty limestone, but containing agglomerate with unsorted, angular, cherty material for the lower six feet, occur at Point Grinder.

Distribution. Outcrops of the formation occur at Bell Point, Point Grinder, and between Bird Rock and The Bluff. The grey-white limestone overlies beds of grey limestone containing agglomerate at Point Grinder, but forms the lowest part of the exposed section at Mushroom Rock. The three stacks at Bird Rock consist of grey-white limestone. These stacks are isolated from the outcrops of brown limestone to the west near Walkerville, although the strike of the brown limestone indicates that these beds underlie the grey-white limestone. At Bell Point, the grey limestone, in an abrupt facies change, conformably overlies the grey-white limestone at Mushroom Rock. Grey limestone and mudstone also occur between Walkerville and The Bluff, and micaceous mudstone is exposed in the road cutting at Walkerville. The outcrops between Bird Rock and The Bluff are not continuous and the break in the section may be due to the presence of more easily eroded sediments and also to the major changes of strike which occur in this locality.

Palaeontology. Fossils are known from the grey-white limestone at Point Grinder, Mushroom Rock and the bioherm to the north, and at the middle stack at Bird Rock. Stromatoporoids and crinoid fragments are common to all localities. A gastropod and cephalopod are known from Mushroom Rock. Corals occur at the Bird Rock locality and at Point Grinder. *Favosites nitida* Chapman has been identified by Dr. Hill from Point Grinder.

The change of conditions which resulted in the deposition of the grey limestone favoured an entirely different assemblage of forms. Some beds are richly fossiliferous. A trochoform gastropod is the only fossil in the lowest 75 feet. Above this, Spiriferid brachiopods occur together with the gastropod. There follows a section of unfossiliferous rocks, above which the beds contain rugose and rare tabulate corals, Spiriferids and other brachiopods and several small species of gastropods, including turreted and turbinate forms. A grey silty limestone bed, faulted against the Digger Island Formation at locality 5, contains *Conocardium* and ostracods. Beds rich in corals alternate with beds rich in brachiopods to the top of the section, although both forms are present in any given bed.

Tabulate and rugose corals, which macroscopically appear to be similar to the corals of the grey limestone at Bell Point, occur in the brown limestone west of Bird Rock. *Amphipora* occurs in the grey silty limestone near The Bluff.

From field evidence, the sequence of rocks in the formation is a basal, brown, silty limestone and mudstone with chert pebbles overlain by grey-white limestone. Above this is grey silty limestone.

Liptrap Formation

Distribution. This formation continues westward beyond Cape Liptrap from its faulted contact with the Bell Point Limestone, west of Point Grinder. Its extent northwards along the coastline from The Bluff, where it is faulted against the Bell Point Limestone, is unknown. The brief examination of the formation was restricted to the coastline between Point Grinder and Cape Liptrap and in the immediate vicinity of The Bluff.

Lithology. The sediments include light grey medium- to coarse-grained quartz sandstone with some bands of grit; dark grey medium- to fine-grained sandstone, interbedded with dark grey to smoky grey and black mudstone and slate, in places micaceous. The coarse sandstone is usually massive or thickly bedded and contains thin veins and stringers of quartz. The conglomeratic material in the coarse sandstone contains chert and green quartzite. The medium-grained sandstone and the mudstone are well bedded and often current-bedded with well developed top, fore and bottom sets. Both the fine-grained sandstone and the mudstone are commonly ripple-marked. The ripple-marks have a wave length of about 5 cm. and an amplitude of ·5 to 1 cm. Subaqueous penecontemporaneous slumping has occurred in some beds of the mudstone.

Palaeontology. Ferguson (1928) recorded fossil plants at Livingstone Creek and a breccia with corals on the Bass Strait coastline, north-west of Cape Liptrap. Solitary and compound corals were found by the writer at several localities along the two miles of coastline north-east from Cape Liptrap. The corals occur in medium- and coarse-grained sandstone and are commonly associated with the pebbles in the conglomeratic bands. Corals also occur occasionally in the slumped beds. The corals are similar to those found in the Sulcor Limestone of New South Wales, which is lower Middle Devonian (Hill, personal communication). However, the lithology and the relationship of the fossils to the coarse-grained sediments are similar to the description of the lithology of the Walhalla Beds in the Walhalla Synclinorium (David, 1950).

The stratigraphic relationship of the Bell Point Limestone and Liptrap Formation cannot be determined in the field, and although the faunal assemblages of both have a Devonian aspect, palaeontological evidence is insufficient at present to indicate their relative ages.

Tertiary Sediments

Distribution. Tertiary sediments overlie the Palaeozoic rocks on the cliff tops and for a considerable distance inland between Walkerville and Point Grinder. They also cap Digger Island. Small outcrops occur at low water level near the fault between the Digger Island Formation and Bell Point Limestone north of locality 3, although these outcrops may not be *in situ*. However, there is a deposit of lignitic material on the foreshore about 15 chains south of Digger Island.

Lithology. The sediments consist of a white, fine quartz-conglomerate and sands. The sediments are poorly bedded and are consolidated, but not well cemented. Rounded to sub-rounded pebbles of milky quartz and rare diabase, 2 to 10 mm. in diameter, are unevenly distributed in a fine sandy matrix. Woody fragments and stumps, partly replaced by pyrite, are common in the lignitic material south of Digger Island. Depending upon the movement of the sand on the beach, the deposit may be over a foot below the surface (as in January 1950), or lignitic

material may protrude through the surface of fine sand (as in February 1948). Under the latter conditions the shape of the deposit may be determined at low tide by the area ringed by water seepages. The deposit measures 90 feet by 60 feet.

The formation is 80 to 100 feet thick in places. However, the thickness is variable and there are two inliers of diabase on the coastal plain, north of Bear Creek.

Age of the sediments. The conglomerate is possibly a beach deposit, as it is much the same in grain size and composition as the present day beach gravels in the gaps in the diabase between locality 1 and Bird Rock, although the gravels are more rounded. The situation of the sands and conglomerate on a level platform close to the present day shoreline also suggest that the conglomerate is a beach deposit.

Uplift of 150 to 200 feet of the conglomerate to its present position was probably connected with the late Tertiary movements in South Gippsland (Hills, 1934), and a Tertiary rather than Quaternary age for the conglomerate is indicated.

Igneous Rocks

Diabase

Included under this title is a group of rocks, most of which were originally basic lavas with associated interbedded tuffs and agglomerates. It is possible that medium-grained igneous rocks were intrusive into the group. Interbedded sediments are rare. Some metasomatism has resulted in the formation of chert and jasperoid rocks.

Extrusive rocks. The rocks are dark, green-grey, dense, fine-grained, even-textured, and weather to a yellow clay soil. Minerals grains are rarely distinguishable and are not identifiable macroscopically. At most localities, deep etching of the surface through weathering, a well developed but irregular joint pattern, and shearing have obliterated the structure and texture of the rocks. Therefore the individual lava flows are difficult to distinguish, except where they are in contact with tuffs. However, near locality 11, silicification over a thickness of several feet has occurred in the diabase and in this zone the original structure of ropy lava flows, several inches to a foot thick, is still visible. Structures strongly resembling pillow lavas occur on the foreshore near locality 11 and also in the cliff face between localities 8 and 9.

Under the microscope, the lava is seen to be typically a fine-grained equigranular rock, composed of granular augite, lath-like, subhedral felspars and interstitial serpentine minerals. Usually the augite crystals are less than 0·2 mm. in diameter and commonly occur in granular clusters. The felspar laths are 0·2 to 0·3 mm. in length, although some sections contain rare, porphyritic, tabular felspar crystals up to 1 mm. in length. The felspar usually is cloudy and kaolinized. Where it can be identified it is andesine, approaching labradorite. A slightly pleochroic serpentine mineral occurs as poorly defined pseudomorphs after olivine, and also as an interstitial and vein mineral. Magnetite is associated with the serpentine. There is usually a little calcite, felspar and quartz present in the joint planes. Pyrite and leucoxene occur in some sections.

The rocks show little sign of the low-grade dynamic metamorphism which is characteristic for the Heathcote (Skeats, 1908; Singleton, 1949) and Howqua areas (Teale, 1919). However, in some sections veins of lawsonite indicate that metamorphism has occurred.

Pyroclastic rocks. Tuffs are recognizable in the field as stratified and banded rocks, commonly containing pebbles which originally were the constituents of a volcanic breccia. The tuffs are usually red-brown, green-grey or grey in colour. Tuff beds occur in the outcrops of diabase along Maitland Beach and are usually 20 to 40 feet thick. The greatest thickness observed was 80 feet. About half a mile south of locality 11, a tuff bed, 50 feet thick, is associated with thin red tuff beds which are alternately bedded with igneous rocks for 100 feet.

Although the bedding of the tuffs has been entirely obliterated in some places—for instance no stratified rocks are seen in the diabase between Bird Rock and locality 1—thin sections from outcrops near the gabbro intrusion near locality 1, and from the diabase immediately adjoining the fault boundary at locality 12, indicate that these massive, macroscopically structureless rock types were tuffs.

Thin sections of the tuffs commonly consist of kaolinized felspar, quartz and calcite; ferro-magnesian minerals are notably absent. In the groundmass, the quartz is in most cases microcrystalline and may occur in aggregates of almost pure silica up to 1 mm. in size, but is usually mixed with and subordinate to completely kaolinized, minute felspar laths. Microcrystalline calcite occurs in the groundmass of some specimens. Calcite up to 0·5 mm. in size also occurs as a vein mineral, associated with quartz up to 1 mm. in size, showing strain extinction. The tuff at locality 12 consists of microcrystalline clay mineral with crystals elongated and oriented in two directions at about 60 degrees.

A large outcrop of a light-brown rock in the diabase near locality 1 appears in thin section, to resemble the siliceous-carbonate rocks described from other areas of diabase in Victoria. Microscopically, the rock is similar in composition to the other tuffs, but contains a much higher proportion of calcite in the groundmass. Veins of calcite are also more common.

Intrusive rocks. Narrow belts, suggesting dykes, occur in the diabase between Bird Rock and locality 1. The rocks are macrocrystalline and appear to be dolerite.

Metasomatism. Localized veins and pockets of jasper occur along joints and fractures and in places large irregular masses have undergone partial replacement by silica with introduction of iron oxide.

A black chert near locality 12 consists of microcrystalline quartz associated with pyrite in veins, in a dark, siliceous matrix. The rock has not been completely silicified and stratification indicates that it was originally either a tuff or a sediment.

The siliceous-carbonate rocks associated with the diabase are regarded as tuffs which have been subjected first to carbonating solutions and subsequently to silica-rich solutions, resulting in cherty patches in a carbonate rock (Skeats, 1908).

Sediments. Outcrops of shale at locality 8 and limestone lenses at locality 7 are the only sediments known to occur in the diabase. The limestone, which is black, fine-grained, dense, and has been recrystallized, occurs in lenses in the diabase near the faulted contact with the Digger Island Formation. The shale is yellow-brown and is strongly sheared. Microscopically, the rock consists of iron-stained clay minerals elongated in the plane of the bedding. Chalcedonic silica is present in veins across the bedding and there was also some selective silicification along certain beds.

Age of the diabase. It has been established that the age of the Heathcotian rocks in Victoria is Middle to Upper Cambrian and older (Skeats, 1908; Teale, 1919). The diabase at Waratah Bay appears to be on the same major structural line as the Howqua belt of diabase, and, having similar lithology, it probably is of

the same general age. No fossils were found in the field in the shale at locality 8, but sponge spicules were found in a thin section of this rock. This discovery indicates that additional material might yield new fossils or allow the proper determination of the sponge.

Gabbro

Outcrops of gabbro are restricted to the vicinity of the fault between the diabase and Digger Island Formation. The extent of the gabbro to the west is not known, as it is overlain by Tertiary sediments.

The gabbro is a medium- to very coarse-grained, equigranular, hypidiomorphic, green rock and has been serpentinized. Crystal size is commonly 2 to 5 mm., but at some localities on the backshore west of Digger Island it is as large as 40 to 60 mm. Opal, which probably originated through liberation of silica during the decomposition of olivine, is present in joints, and calcite and limonite are common vein minerals.

Thin sections indicate that the gabbro was originally a group of basic plutonic rocks, rather than one rock type. Newberry (1877), in a laboratory report on specimens from Waratah Bay, records the presence of plagioclase and a uralitized diallage, and named the rock gabbro. This name is retained for convenience until further work indicates the various rock types present.

A section of the medium-grained rock contains serpentine, saussuritized felspar and calcite. Serpentine occurs as complete pseudomorphs after subhedral orthopyroxene, probably enstatite. The saussuritized felspar shows relict twinning and was probably labradorite. Calcite occurs in veins. The coarse-grained gabbro consists largely of subhedral saussuritized felspar and interstitial serpentine after olivine. Serpentine also occurs in veins. Leucoxene is present in the cleavage planes of the pseudomorphic serpentine. The felspar was originally labradorite and shows relict lamellar and Carlsbad twinning.

The intrusion of the gabbro resulted in low-grade thermal metamorphism of the diabase and Digger Island Formation. The gabbro has not been sheared and it is therefore younger than the fault which provided a passage for the intrusion.

Structure

Major Faults

The Palaeozoic formations exposed along the west coast of Waratah Bay are separated by a system of faults with a general northerly trend. Along the shoreline, the fault zones have been severely affected by weathering and therefore little information regarding the nature of the faulting can be obtained.

The Bluff-Point Grinder Fault

At The Bluff, a faulted contact between the Liptrap Formation and Bell Point Limestone has been revealed by the quarrying of limestone. The pug zone is 150 feet wide and dips steeply to the west. It contains lenticular pebbles of limestone, sandstone and mudstone. The Bell Point Limestone, along the eastern face of The Bluff, shows calcite veining over a distance of 150 feet to the east of the fault. The Liptrap sediments immediately to the west of the pug zone are strongly folded and sheared. On the foreshore at The Bluff the pug zone is eroded below the level of the shore platform and is covered by sand; the gap between the sediments on the foreshore strikes 30 degrees and the sediments on either side 10 degrees.

West of Point Grinder, a gap of 160 feet separates the grey-white limestone of the Bell Point Limestone from sandstone of the Liptrap Formation. The limestone within 80 feet of the contact is sheared and fractured and is extensively veined by calcite along the fractures. The dips of the sediments on either side of the gap are steeper than elsewhere, and decrease beyond 160 feet. Calcite veining in the limestone and local steepening of the dip in both formations is regarded as evidence of faulting. In the map (Fig. 3) this fault is shown as the continuation of the fault at The Bluff, which involves the same formations.

Fault between Bell Point Limestone and Diabase

At Point Grinder, the contact of these formations can be studied in plan on the wave-cut platform at low tide over a distance of 1200 feet. The contact is regarded as a fault, because a brecciated zone usually 6 to 8 feet in thickness occurs between the two formations. The diabase is strongly sheared for more than 100 feet from the contact, with west dipping shear planes, although the diabase itself appears to dip steeply to the east. The limestone at the contact contains slickensided calcite along numerous shear planes. The diabase, limestone and brecciated zone in the vicinity of the fault strike at 15 to 20 degrees and dip 55 to 65 degrees to the west. The size of the brecciated fragments in the fault zone range from 1 to 8 cm.

South of Bird Rock, the contact between the diabase and Bell Point Limestone is transverse to the bedding of the limestone and is therefore faulted. Evidence of faulting is substantiated by the partial recrystallization of the limestone and calcite veining, and shearing of the diabase. Boulders of diabase along the contact are impregnated with limonite.

Fault between Digger Island Formation and Diabase

Between localities 6 and 7, a fault zone separates these formations. The gabbro, which is exposed at locality 6 and other localities further north, separates the diabase from the Digger Island Formation, and was intruded along the fault which separates the two formations. The fault zone is nearly vertical, although one reading indicated a steep westerly hade. The limestone east of the fault dips steeply east. The fault zone, with an intimate mixture of sheared diabase, calcite and recrystallized limestone, is 150 feet wide.

Fault between Digger Island Formation and Bell Point Limestone

There are no outcrops in the fault zone separating the Digger Island Formation and Bell Point Limestone between localities 2 and 3, but the outcrops of the Bell Point Limestone adjacent to the fault zone both here and at locality 5 are strongly veined with calcite. Close to the fault, the limestone dips steeply to the east, which is in contrast to the general westerly dip. This indicates the direction of throw of the fault. The limestone is also more folded in the vicinity of the fault than elsewhere, and the folds are commonly fractured, the fractures hading steeply to the east.

Age of the Faulting

The gabbro is younger than the fault between the Digger Island Formation and the diabase. The faults in the area are probably of the same age and connected with the orogenic movements which folded the rocks in the area. Limonite and calcite infilling of joints in the gabbro, with some slickensiding, is probably a

result of later small-scale movements. The main movement pre-dated the deposition of Tertiary sediments because the scarp between Point Grinder and The Bluff is a consequent fault-line scarp and has been partly covered by the Tertiary sediments. West of The Bluff, in the vicinity of the fault contact between the Liptrap Formation and Bell Point Limestone, a bed of Tertiary pebbles has been displaced 12 feet by a downward movement on the western side of the fault. The faulting is post-Devonian sedimentation and pre-dates both the gabbro and the Tertiary sediments, with slight post-Tertiary movement.

Structure of Sedimentary Rocks

Digger Island Formation

Folding in this formation is restricted to shallow cross-folds which are common on Digger Island, making dip and strike readings unreliable. Small-scale faults, which range in strike from 340 degrees to 20 degrees and hade steeply in a westerly direction, were observed on Digger Island. On the eastern side of the island, calcite is associated with horizontal slickensides along the fault planes. Fossils are commonly sheared.

Two sets of joints, almost at right angles, are developed in the outcrops on Digger Island. The trends are north-north-west and east-north-east and dips are steep to the west and north. Jointing is well developed in the contact metamorphic zone with the gabbro.

Bell Point Limestone

The main structural trends of this formation are illustrated in Fig. 2. The folds are shallow and usually in the nature of asymmetrical flexures, which plunge to the north. The folding is more intensive near the major fault separating the formation from the Digger Island Formation, but the folds remained shallow and relief of compression was affected by small break thrusts of a few feet.

Jointing is well developed near the faulted contact with the diabase near Bird Rock.

Liptrap Formation

The sediments of this formation are strongly folded, but the folds have not been mapped as this would involve much detailed work. Near Cape Liptrap, the cliff sections at the heads of the rocky coves illustrate the complexity of the folding. In general, the strike ranges from north to 30 degrees, with dips rarely less than 60 degrees and frequently approaching 90 degrees. At Point Grinder, the beds are vertical or dip steeply west for some distance to the west of the faulted contact with the Bell Point Limestone, and easterly dips are rare.

The beds are sheared and tension gashes filled with quartz have been observed associated with quartz veins in the medium- and coarse-grained sandstones. The fine-grained sediments are commonly fissured at the apices of folds and in crush zones. Dip faults and oblique faults are common.

Numerous beds of dark-grey and black mudstone are closely folded, sheared and contorted. Incorporated within these beds are thin layers of medium and coarse sand, large blocks and balls of sandstone and mudstone, and numerous pebbles of well rounded and tabular quartz and slate. The folding was produced by subaqueous penecontemporaneous slumping, because the overlying and underlying beds conform with the regional structural pattern.

Structure of Igneous Rocks

Diabase

The structures and textures of the igneous rocks are largely obliterated as a result of diastrophic movements. The associated pyroclastic rocks and interbedded sediments give the only structural indications.

Dips are steeply to the west or vertical except for a steep easterly dip of a bed of chert at locality 12, and in strongly sheared tuffs near the faulted contact with the Bell Point Formation at Point Grinder. Faults have been observed at localities 9, 10 and 11. The formation is strongly but irregularly jointed. Main trends of faults and joints are northerly and approximately 100 degrees.

Gabbro

The gabbro is massive and, as mentioned before, evidently younger than the fault between Digger Island Formation and the diabase. Calcite and limonite veins along the numerous joint planes in the weathered gabbro give it a honeycombed appearance. The largest of these joints trend northerly and show near-horizontal slickensiding of the calcite.

Conclusion

The most obvious feature of the structure of the three Palaeozoic sedimentary formations at Waratah Bay is that folding has been most intensive in the Liptrap Formation and least noticeable in the oldest formation, the Digger Island Formation.

Ferguson has mapped Upper Ordovician fossiliferous slates and sandstones 4½ miles north-west of Walkerville, near Ten Mile Creek and at Bald Hill, further north. The continuation northwards of this belt of Ordovician has been termed the Waratah-Boolara Anticlinorium (Thomas, 1939). The belt of diabase along the Waratah Bay coastline has been termed the Waratah Axis. In between these structural axes, with Lower Palaeozoic rocks exposed in the cores, is a belt of closely folded Devonian sediments with predominating westerly dips between Point Grinder and Cape Liptrap. This suggests a synclinal area, five miles across, defined by boundary faults against the Waratah Axis so that rocks of Ordovician and Silurian age are not exposed on the east side of the synclinal area west of the Waratah Axis. Baragwanath (1925) has suggested the possibility of a continuation of the Walhalla Synclinorium to the south as far as Cape Liptrap.

Geomorphology

Cape Liptrap Peninsula

The streams draining the eastern side of the peninsula are deeply incised into a low scarp between Point Grinder and Walkerville and into a small plain which extends from the base of the scarp at about 200 feet above sea level, to the coastline. The streams are consequent with steep-sided, straight valleys and little or no accumulation of alluvium in the valley floors. The interfluves are wide and there is little development of insequent tributaries reducing the width of the interfluves. Bear Creek is an example of an engrafted stream. The plain is still in the stage of early youth.

If the distribution of sands, clays and gravels marked Tertiary on Ferguson's plan is correct, and this has been partly verified by examination along the coast and in some creek beds on traverses inland, then the plain can be envisaged as a

coastal plain, following a late Tertiary emergence of a marine platform, of at least 150 feet. Torrent gravels, with well rounded quartz pebbles, occur about 140 feet above sea level at Bairnsdale. Tertiary sediments occur up to 250 and 270 feet above sea level at Fernbank between the Avon and Mitchell Rivers, in the neighbourhood of the Gippsland Lakes (Hart, 1922). The East Gippsland coastline was uplifted in post-Lower Pliocene time and is now being modified by submergence.

Coastline

Structure and the various rock types influence the configuration of the coastline. Between Point Grinder and Cape Liptrap and north of The Bluff the coastline is either sub-parallel to or normal to the consistent regional strike of the Liptrap Formation (Fig. 3). South of The Bluff the coastline is mainly in the structureless diabase, and swings in a south-east direction to Bell Point and then to the south-west to Point Grinder. The headlands are composed of sandstone (Cape Liptrap) and limestone (Point Grinder, Bell Point, Bird Rock). The sandstone cliffs are higher than those of limestone. The diabase shoreline is rocky, with frequent gaps a few feet wide forming deep clefts to the backshore or the base of the cliffs. Occasional open stretches occur along the shore, but these are not large enough to be termed pocket beaches. Landslips occur in the cliff regions of the diabase when the cliffs are undercut by wave action on the deep-weathering diabase.

Wave-cut Platforms

The influence of rock types and power of wave action in the formation of wave-cut platforms is well exhibited. The grey-white limestone of the Bell Point Limestone at Point Grinder, Mushroom Rock and Bird Rock has a well developed and level platform, truncating beds which dip from 65 degrees to 25 degrees and strike in varying directions. Wave-cut notches at the base of the cliffs are also well developed. On the exposed sides of Point Grinder (south-west) and Mushroom Rock (east) the platform is narrow. On the eastern side of Point Grinder, which is sheltered from the heavy seas and south-westerly gales of Bass Strait, the wave-cut platform extends from the limestone cliffs to the faulted contact with the diabase. Platforms on the grey limestone of the Bell Point Limestone are poorly developed, although structural conditions are similar to those of the grey-white limestone. The platforms are narrower, have an uneven surface, and merge with the cliffs and stacks at high water level without the development of wave-cut notches.

An extensive platform is formed on the sediments of the Liptrap Formation at the head of the broad bay between Point Grinder and Cape Liptrap, where the shoreline is normal to the consistent strike of steeply or vertically dipping sediments. The platform has a peculiar appearance at low tide, as selective erosion of alternately bedded shale and sandstone has given the appearance of a coarsely ploughed field. Near Cape Liptrap, where the shoreline is parallel to the strike, the wave-cut platform is absent or poorly developed as selective erosion of the sediments has left the massive sandstone beds protruding as bars and rocks.

The surface of outcrops of diabase is very uneven along the shoreline. Selective erosion along ash beds, shear zones and irregularly spaced joints has prevented the formation of a platform, but there is a general upper surface, which is capped only rarely by a harder mass of diabase, shelving gradually seawards.

There is no wave-cut platform on sediments of the Digger Island Formation.